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Page 2

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AMENDMENTS TO THE SPECIFICATION

Federal Research Statement

A¹ ~~[Federal Research Statement Paragraph]~~ The U.S. Government has a paid-up license in this invention and the right in limited circumstances to require the patent owner to license others on reasonable terms as provided for by the terms of contract No. N00024-97-C-4208 awarded by the Naval Sea Systems Command of the United States Department of the Navy.

A² [0018] It is another object of the present invention to provide a rapid method of taking true root-mean square ac measurements, especially at high frequencies.

A³ [0019] An opto-electric device for measuring the root mean square value of an alternating current voltage comprises : a) an electric field-to-light-to-voltage converter having 1) a light source; 2) an electro-optic material: (a) receiving light from the light source; (b) modulating said light; and (c) providing a modulated light output; 3) an electric field applied to the electro-optic crystal to modulate the light from the light source to produce the modulated light output; b) an optical receiver for receiving and converting the modulated output light from the electro-optic material to a first voltage that is proportional to a square of the electric field applied to the electro-optic material; c) an averager circuit receiving the first voltage and providing a second voltage that is proportional to the average of said square of said electric field over a period of time; and d) an inverse ratiometric circuit receiving the second voltage from the averager circuit and returning a third voltage that is an inverse voltage of the second voltage to the electric field-to-light-to-voltage converter to produce an output voltage that is the root mean square voltage of the applied electric field. The device uses a Mach-Zehnder interferometer operating as a square law device and features a housing for maintaining the interferometer at constant temperature using a temperature control unit. A nulling circuit is provided to maintain the interferometer at its null operating point as are calibration circuits to correct for voltage amplitude and frequency changes.

A⁴ [0039] With reference to the drawings and initially Fig. 1, a measurement device 10 for measuring the true root-mean-square value of an alternating current comprises an electric field-light-voltage converter 70 with a light source 20, electro-optical device 30 for receiving and modulating light 22 from the light source 20 as a square law device under the influence of an electric field produced by an input voltage from line 28. The

AMENDMENTS TO THE SPECIFICATION

A4
modulated light 32 is received by an optical receiver 40 to produce a first voltage that is proportional to the square of the input voltage in line 28. The first voltage passes to an averager 50 by means of connection 42 where averager 50 provides a second voltage that is proportional to the average of the square of the electric field over a period of time. The voltage output in line 52 is then feed to an inverse ratio circuit 60 that returns an inverse voltage of the voltage in line 52 to the electric potential-light-voltage converter 70 by means of line 62. By feeding back the inverse voltage to converter 70, an output voltage is produced in line 54 that is the root mean square voltage of the applied electric field produced by the input voltage in line 28. Typically the output voltage in line 54 is used in conjunction with a high-precision digital dc voltmeter for display of the true rms voltage.

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[0045] Light Source Module 20. Referring to Figs. 1-6 and especially Figs. 2 and 6, the light source module 20 comprises a light source 21 selected to provide electromagnetic radiation 22 in the infrared to the ultraviolet region. Preferably a light source 21 such as a light-emitting diode (LED) or infrared-emitting diode (IRED) such as are commonly used in fiberoptic technology is used. Most preferred is a source of at least some coherent radiation such as found in lasers or laser diodes such as the Ortel 1710B DFB (distributed feedback) laser (Ortel Corporation (Alhambra, CA, a part of Lucent Technologies" Microelectronics Group). The Ortel laser 21 operates at 1550 nm and includes an optical isolator to prevent optical feedback into the cavity causing intensity and frequency disturbances. It is connected to the electro-optic module 30 by means of a pigtail polarization maintaining (PM) fiber 27. The normal operating range of the laser is about 3mW to 30mW with a maximum rated power of 35mW. The laser diode has a threshold drive current of 2.5 mA with about 220 mA required for a 30 mW output. The Ortel diode 21 was used with a Melles-Griot Power Source Package (06DLD203A; Boulder CO) 160 that consists of a light source driver 24, a light source temperature controller 25, and an input interface connection 26 for connecting the driver 24 to the input control voltage in line 62 received from the inverse ratio circuit 60.

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[0052] As shown in Fig. 9, an integrated Mach-Zehnder intensity-type modulator arrangement 30 takes advantage of the interference effects of two interacting light beams. For this purpose, wave guides are formed typically by diffusing a metal such as titanium into a crystal substrate 31 such as lithium niobate in

AMENDMENTS TO THE SPECIFICATION

A6
the requisite configuration. As shown, light 22 is received at waveguide 33, divided into two paths 34 and 36 and then recombined in path 38. A phase shift in the light is induced by a change in the refractive index of the crystal material in one or both of waveguide legs 34, 36 caused by applying an electric field to one or both of these waveguides 34, 36. As shown, the electric field is applied by means of electrodes applied to the substrate. As illustrated, two sets of electrodes are used. A first set of electrodes for DC bias nulling operations to maintain the device at the desired operating point and a second set for applying the radio-frequency (RF) test voltage. The nulling electrodes consist of two hot electrodes 142, 142' placed to the outside of waveguides 34 and 36 and a ground electrode 144 placed between waveguides 34 and 36. Each of the electrodes is about 9 mm long with a 10 Φ mum gap between the ground and hot electrodes. The electrodes are typically made of gold and applied using photolithographic processing. The input electrodes are about 12 mm long, again with a 10 Φ mum gap. Again two hot electrodes 35, 35' are placed at the outside of the waveguide padpaths 34, 36 while the ground electrode 37 is placed between them. One set of electrodes can be eliminated by using a bias T arrangement in which both the dc null bias voltage and the radio-frequency input voltage use the same set of electrodes. In this situation a resistor is used in series with the dc bias input and a capacitor is used in series with the ac input.

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[0056] To this end and as shown in Fig. 9, the integrated Mach-Zehnder interferometer of the current invention was designed with a small amount of asymmetry, i.e., waveguide 34 is slightly longer than waveguide 36 to place the intrinsic or natural bias point close to the central null. That is, light passing through legs 34 and 36 of the interferometer will destructively interfere with each other so that no light emerges from waveguide 38 prior to (without) the application of a voltage to the interferometer electrodes. That is, the intrinsic or normal operating point is at point A as shown on the bias curve of Fig. 10. If the legs are constructed equal to each other, all of the light emerges as a result of constructive interference of the light in legs 34, 36. Certainly it is not necessary that the interferometer be constructed so as to operate close to or at the null point A. As is known in the art, a small biasing voltage can be applied to bring the operating point of the interferometer to the linear operating point C. So totoo is the case with the current invention. A biasing voltage in lead 145 can be applied to electrodes 142, 142' to bring the interferometer to squarer operating point regardless of the symmetry of the interferometer legs 34, 36. The slight

AMENDMENTS TO THE SPECIFICATION

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asymmetric construction noted above serves mainly to afford an interferometer requiring a minimum biasing voltage.

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[0061] Typically the electro-optic modulator is mounted on a small printed circuit board (pcb) 88 which in turn is mounted to a closed or sealed housing 80. Because the bias required to maintain the electro-optical squarer at its optimum null bias point is a function of temperature, the squarer 30 is maintained in an oven like enclosure 80 that is maintained at a temperature of about 38 ± 2 °C. HA temperature control unit 90 comprises one or more heating devices, e.g., heaters 82, which are provided within housing 80 and which are used in conjunction with a temperature sensor, e.g., thermistor 886 and a heater controller 84 to maintain the optical modulator at a constant temperature. A 50 Ω surface mount resistor is placed in parallel with the electrodes to provide the correct termination and govern the input impedance of the device and its power dissipation limitations.

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[0064] As seen in Fig. 17, the heart of the AC calibration source is oscillator 112. The output is connected to a commercially available root-mean-square (RMS) converter 117. The DC output of the RMS converter is compared to a stable reference source 116 with control loop amplifier 115. The output of control amplifier 115 is connected to multiplier 114. The other input of the multiplier is connected to the output of oscillator 112. In this configuration, the multiplier is in the feedback loop of the oscillator 112 and affects the feedback resistance, thus the gain. This results in stabilizing the RMS output of the oscillator to equal the stable DC reference voltage.

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[0070] In the Calibration mode, an AC calibration source is applied to the Electro-Optical True RMS Converter 30. The AC calibration source operates at the pivot frequency of 1 kHz. The voltage amplitude of the AC source is varied from 10 mV to 100 mV in steps of 10 mV. The response of the instrument, V_{out} is measured and stored in a voltage lookup table 101. In the Measurement mode, the unknown AC voltage is connected to the optical squarer and the response of the instrument, V_{out} is measured. This value is compared to the stored values in the look-uplookup table 101 and a correction factor is applied to the measured value of the unknown

AMENDMENTS TO THE SPECIFICATION

A10
voltage. This calculated value is multiplied by a second correction factor due to the frequency of the unknown voltage. The frequency of the unknown AC voltage is measured using a frequency counter. The frequency lookup table 103, created in the factory, is looked up to find the correction factor and the true RMS value of the unknown voltage is displayed. Additional explanation of calibration techniques can be found in US 5,440,113, US 5,317,443, US 5,003,624, US 5,012,181 and US 4,859,936 all of which are incorporated herein by reference as if completely written herein.
